Medical Officers of Schools Association.

9.

VENTILATION
AS A DYNAMICAL PROBLEM.

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With the Subsequent Discussion.

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Ventilation as a Dynamical Problem.

I WILL begin by calling attention to a few points of special and fundamental importance.

I.—Inlets and Outlets.

The first point is concerned with the numerical relation between the volume of air flowing through the room to be ventilated, and the motive power which maintains the flow. I need hardly repeat that steady ventilation requires openings for air to come in, openings for air to go out, and motive power to keep a steady current flowing through these openings. The motive power I shall call the "head" or "aeromotive force," and shall suppose it to be estimated by the number of foot-pounds of work required to get a pound weight of air into the room and out again in the course of the ventilation. The mode of estimation is a complicated one, but "head" is also equivalent to pressure-difference, a more familiar idea, and "aëromotive force" is selected on the analogy of "electro-motive force" for special reasons that will appear later. Be the names good or bad, the head is closely related to the horse-power spent in maintaining the ventilation current. If, for example, 5 h.p. are being spent, causing a current of air measured at 100 cubic ft. per second, the head is $\frac{5 \times 550 \times 12 \cdot 8}{100}$ or 352 ft., equivalent to about 5 inches of water pressure.

The "head," or "aëromotive force," for ventilation may arise in three ways—from wind, from shafts carrying warm air, and from fans or blowing machines. The first source of power for ventilation purposes is called natural, the second may be called thermal, and the third mechanical. The "natural" head varies as the square of the velocity of the wind; and the ventilation produced by it, either directly or indirectly, varies as the velocity of the wind; the "thermal" head is proportional to the difference of the temperatures within and without the shaft; the "mechanical" head depends upon the machine

* See a table in Stevenson and Murphy, Hygiene, Vol. i., page 84.

employed; with rotating fans it is proportional to the square of the velocity of the tips of the vanes.

What I wish now specially to point out with regard to this matter is that, if the head be compared with the flow it produces, it will be found that it is numerically proportional to the square of the flow for any simple ventilation circuit. The ratio is proportional to what may be called the combined resistance of the inlets and outlets, depending upon the shape and size of those areas. Work is spent in getting a cubic foot of air into a room and out of it again in many different ways; velocity has to be generated, corners have to be turned, bends rounded. It appears, from experiments into which I will not now enter, that all these demands upon the energy required for the passage of a single cubic foot of air are proportional to the square of the rate of travel of the cubic foot, and not to the simple current. In fact, the only item in the expenditure of energy which is simply proportional to the velocity is the friction in a long tube, and this, generally speaking, contributes only a small part to the whole resistance of the circuit.

I have verified by careful experiments upon a chimney that the law of proportion of head to the square of flow is very closely accurate. It follows—and this is the point at which I want to arrive—that the power required for a certain flow is proportional to the cube of the flow, and the conclusion to which I wish to draw special attention is that, under these circumstances, it is the resistance of the circuit, depending upon the magnitude of inlets and outlets, that is the critical factor in ventilation. It is useless to attempt to compensate for small inlets and outlets by more energetic machinery. Let me give some examples. Suppose you have an arrangement of inlets and outlets which, with a certain horse-power, affords ventilation for 100 persons, and you desire to accommodate 200 persons. To do so without altering the inlets and outlets would involve eightfold expenditure of horse-power. Or, again, a room with a fire in it will accommodate five persons comfortably, the fire supplying motive power for the necessary ventilation. If you put ten persons into the room and leave the inlets and outlets as they were, you ought to double the flow to accommodate the additional persons. It might be thought that you could get the extra flow by making up a more vigorous fire. It would require eight times the fire to secure the object, and perhaps I cannot more conclusively illustrate the dominant influence of the size of openings upon ventilation than by asking you to imagine the result of attempting to increase a fire to eight times its original size for the sake of accommodating five additional persons.

I have been asked to say something with special reference to the provision of ventilation in buildings already existing:

and I desire to say particularly this, that for the ventilation of any building, existing or non-existing, you must have adequate holes for the air to come in by and go out by. No mechanical contrivance can make up for the want of sufficient inlets and outlets. You may consider afterwards whether what comes in or goes out is precisely what you want, or do not want, as regards temperature and other matters, but do not attempt to make up by increased motive power for the want of area in inlets and outlets.

I should like to say a word or two about the casual openings that constitute the only source of air for ventilation in many inhabited rooms. It was an unfortunate day for ventilation when Pettenkofer succeeded in blowing out a candle by means of air driven through a brick. It is an interesting experiment, but it is not safe to draw from it the conclusion that provided the walls of your house are of brick no further provision for ventilation is needed, and yet implicitly this conclusion has been the basis of a good deal of action or of inaction in the matter of ventilation.

Casual openings of many kinds make up for the want of effective porosity of brick walls covered with plaster and wall-paper. Chinks in windows, doors, and floors all let in a certain amount of air to a room that has a fire to produce sufficient head for ventilation. I should estimate that sufficient air for three, or perhaps four persons, would be found to come in that way. If more than four persons are in a room the casual openings are no longer sufficient. Hence the arrangement that is good enough for a single bed-room, a study, or a sitting-room for three or four persons, is not adequate for a school class-room. In such a case you must count the persons to be supplied with air, and make the provision that you consider necessary to supply them. The chinks and casual openings become negligible in comparison with the special openings required, as soon as the number of occupants of a room becomes more than at the rate of, say, one per hundred square feet.

II.—Transmission of Power.

The second special consideration to which I desire to draw attention is more particularly applicable in the case of mechanical ventilation. It is this,—that one of the items of expenditure of energy in driving air through shafts is the actual production of velocity. My hearers will remember kinetic energy as one of the forms of energy, and the production of kinetic energy in ventilation currents is an important consideration. With ordinary arrangements for ventilation, kinetic energy is produced in the inlets and in the outlets, which are very narrow apertures compared with the dimensions of the room to be ventilated. If

the head for ventilation is produced by a single agent—a fan or a chimney—this is generally placed in one of the narrow channels. The energy necessary to get up the velocity in the second channel has to be "transmitted" from the source of power, the fan or chimney as the case may be. Now there are special considerations attaching to this pneumatic transmission of power: for one thing, it is transmitted to all openings, whether intended for the purpose or not; and, secondly, the low pressure fans in general use for ventilation purposes, are very uneconomical agents for transmitting energy: a good deal of power is apt to go to waste in the attempt. I conclude from this that where it is necessary to have considerable velocity in two separate portions of an air circuit, as in inlets and in outlets, it is better to have also separate means of producing the velocity. For producing velocity in outlets, chimneys as well as fans are available: for producing velocity in inlets without transmission of power, chimneys are not available: hot air may be so in a few special cases, but as a rule a fan is the only resource. A special advantage of avoiding the pneumatic transmission of power here spoken of, is that the air pressure in the room itself need not be either above or below that of the outside, so that open windows or doors need not disturb the regular course of the ventilation. This is a very important matter.

III.—Thermal Convection.

The third point to which I wish to direct your attention is concerned with the admission of air to a room, and its relation to the temperature of the room. I think the tendency, or rather the determination, of warm air to rise to the ceiling, and cold air to sink to the floor, is only imperfectly realised, as a rule. A few experiments would convince you that if you admit cold air to a room you may seek it successfully at the floor, no matter where you put your inlets; if, on the other hand, your air is admitted warm—warmer than the air already in the room—you must get a step-ladder if you want to find it. No mechanical arrangements that I know of will induce relatively warm air to reach persons near the floor until it has exhausted all the possibilities open to it at the ceiling; and, on the other hand, no arrangement of Tobin tubes or fine jets will induce cold air to float in warmer air for the benefit of the occupants of the room. The wonderful persistence with which cold air in crowded churches manages to reach one's feet—hidden away inaccessible to everything but cold air—is a striking indication of the inexorable laws of convection. Many important consequences follow from the recognition of these facts. To introduce warm air for the purposes of ventilation in a room

lighted with gas is to waste it. It makes its way forthwith to the upper part of the room, which the gas fumes have appropriated for their own uses. If, however, there is no gas and warm air is introduced, it is desirable not to let it escape until it has come down to the level of the people who are to breathe it, otherwise its purpose fails. Hence, in a system of ventilation and warming which depends on warmed air, the extraction openings should be near the floor.

IV.—Quantity of Air Required.

I have still another point to put before you for special consideration. It is concerned with the amount of air necessary for efficient ventilation. You will know that the amount has been set at about a cubic foot per second, or somewhat less, for each person, and that that is regarded as an extravagant and impracticable amount by most practical ventilators. It is arrived at by a consideration of the amount of air necessary to dilute the carbonic acid, which is taken to be an index of the impurity. I have recently had to consider the matter from another point of view—that of temperature. In many cases you may notice that the effect upon temperature of the persons present in a room is unimportant, because the loss of heat through walls and windows is a most conspicuous factor; but in such places as your school chapels, where the number of persons present is very large compared with the cooling surface, the change of temperature during occupation is a very good index of the efficiency or inefficiency of the ventilation. I have calculated the rise of temperature which an adult person would cause in 3,000 cubic feet supplied to him in one hour, on account of his own combustion, and I find it to be about 5° F. You will probably agree with me that a properly warmed and ventilated chapel ought not to vary in temperature by more than 5° F. during occupation—say, from 58° F. to 63° F.—and I can commend to your notice for the purpose of examining your chapel arrangements a self-recording thermometer. I think you may find that unless you make the liberal allowance of 3,000 cubic feet per hour for each of the congregation you will get a greater rise in temperature than 5° in the hour, as well as too much carbonic acid.

V.—Ventilation as a Dynamical Problem.

I now propose to turn to the consideration of the general problem of ventilation. Ventilation problems are dynamical problems, but in some respects they are so closely analogous to corresponding electrical problems, that I may be pardoned

for drawing attention to the analogy: you will find it of immense assistance in all practical applications.

The analogy can be built up from the simplest examples. A simple electrical circuit consists of a battery, which has an electromotive force and resistance, external resistance and connecting wires. A simple ventilation circuit (for a single room) consists of the moving agent (*e.g.*, a chimney and fire), which has aëromotive force and resistance, external resistance (the resistance of inlets) and connecting spaces (the room and the external air).

A second independent ventilation circuit (for a second room) can in like manner be resolved into a second aëromotive force, resistance and connecting spaces, and be represented by a second electric circuit with its electromotive force, resistances and connecting wires. The two ventilation circuits are connected because one of the analogues of connecting wires—the external air—is common to both circuits. If the rooms are adjoining rooms with a door between them they have a second connexion.

The law of relation between aëromotive force, flow and resistance, $A = V^2 R$, is different from the electrical law (Ohm's law), $E = C R$, in that the pneumatic flow (V) enters as a squared quantity, while the electric current (C) enters in the first power; but otherwise the analogy can be followed to any of its consequences.

If we work out the analogy for a house of several floors, we get a very complicated and intricate problem; aëromotive forces exist wherever there are fires, wherever there are openings exposed to wind, and wherever there are fans. There are also subsidiary aëromotive forces between rooms on different floors, owing to differences of temperature between the inside and outside of the house. Resistances exist for all channels of entry, ventilation openings, window or door openings, chinks, "cold" open chimneys, &c., and for all channels of exit. In an ordinary house the latter are generally limited to the chimneys that have fires in their grates, unless there are openings on opposite sides and wind enough to make use of them; but, just as, with a complicated electrical network, we can follow along with the current all round a complete circuit, and taken the sum of the products of current and resistance to be equal to the algebraic sum of all the electromotive forces in the circuit; so we can follow along the ventilation circuit into the building by any practicable path and out again, and take the sum of the products of the resistance and the square of the flow in each part to be equal to the algebraic sum of the aëromotive forces; or, in other words, to the effective "head" for that circuit.

The complication thus indicated when a building of many

rooms is dealt with is somewhat appalling. So is the corresponding complication of the electrical analogy ; but it is the complication which exists in nature, and it is merely burying one's head in the sand to act as though the ventilation of a building were a simple pneumatic problem.

As compared with the electrical problem, the pneumatic or ventilation problem, is still further complicated by the necessity for considering "draughts," or the distribution of air in the connecting spaces, whereas in electrical problems the distribution of currents in the connecting wires need not be considered. Even without this additional complication, I doubt if anyone would attempt to determine practically the distribution of currents in so complicated a network ; but, in those cases, electricians do not shut their eyes to two-thirds of the elements that have to be considered, and say the remainder affords a practicable problem ; they would reduce the conditions, and insulate the circuits until the necessary simplicity was realised. Progress in ventilation will not be really effective until a corresponding plan is adopted for the pneumatic problems.

Let me briefly classify the systems of ventilation from the point of view of the electrical analogy.

There is the "natural" system, depending on more or less simple openings for inlets and outlets, and upon wind for aëromotive force. I confess to not knowing enough about the wind to be able to go far into numerical calculations with this system. I have made some attempt in a Report on the Dormitories of Poor Law Schools ; but it is inevitably based on averages with which individual cases do not necessarily correspond.

The plenum system provides a single dominant aëromotive force in one inlet. It achieves comparative simplicity by closing as far as possible all openings except those intended by the ventilating engineer for his own use.

The vacuum system, on the contrary, puts the single dominant aëromotive force in the outlet, and takes in air from various sources, casual or otherwise. The effective reduction to a simple form is not nearly so complete as with the plenum system.

In passing it may be useful to remark that the happy-go-lucky system of the ordinary London house is not by any means so bad or unscientific as might be supposed. In this case the aëromotive force arises from fires in grates at the foot of chimneys which form the outlets. The inlets, when they are not open windows, are casual ; they include too many openings in the basement, which supply air primarily to the kitchen department, to be carried up to the fires above stairs mixed with the smell of cooking. But the inlets also include the cold flues, and I think it will be found that in many cases

the cold flues afford the most effective and permanent air supply of a house when the windows and basement door are closed.

This mode of supply has many advantages. It takes the air from above the roof, where it is free from the impurities of the streets. It is true that the opening from which the air is drawn is perilously near the openings of chimneys which are delivering smoke, and that in times of fog there is a good deal of smoke mixed with the air. But, on the other hand, the occasional fire in the grate at the foot of the chimney purifies the air channel even more effectively than dusting out a channel exclusively reserved for inlet purposes, and the layer of soot may act also to some extent as a disinfectant. Moreover, the flues are all in the party walls, and the cold flue is probably between two, or at least adjoins one that carries away the smoke of an active fire, so that the incoming air is moderately warmed by the time it gets into the rooms. With an allowance of two cold flues to one active fire a very reasonable system of ventilation would be maintained, sufficient in the aggregate for, say, three persons per fire—a moderate estimate for a London household.

VI.—Draughts.

As already mentioned, the treatment of ventilation problems by the electrical analogy omits a very important aspect of the question, namely, the distribution of currents in the ventilated space. This is the much discussed question of draughts. In speaking of a discussion upon ventilation at the Sanitary Institute last year, a prominent sanitary authority remarked to me that no one of the speakers had defined a draught. I am going to attempt a definition; you may take it for what it is worth. I will define it as the perception of cold air in a vitiated atmosphere. I desire by the wording of the definition to indicate collaterally, first, that a draught is partly a subjective phenomenon—one man's draught is another man's fresh air—and, secondly, that in the open and fresh air, draughts properly so called do not exist. To avoid draughts, therefore, *keep* the air fresh, and if you do not avoid all the evil consequences you will avoid some; but do not arrange matters so that the atmosphere first becomes seriously vitiated and then partially replaced by cold currents. You would then get a real draught. I am not a physiologist, and I do not understand these matters, but I imagine it possible that the human organism, in arranging things to contend with the poison of vitiated air, makes a certain disposition of its forces, and in arranging things to face the cold, adopts another disposition; and further, that when you ask it to adopt both dis-

positions at the same time you demand too much, and the consequences are disastrous.

Draughts are of two kinds : one is due to the actual entrance of streams of cold air into a room, and the other is due to the formation of streams of cold air in the interior of a building by the cooling effect of window surfaces, when the outside air is very cold compared with the interior. There is no way of preventing the first without restricting the ventilation, except by warming the incoming air. I have already spoken of the relation of the temperature of air to its distribution on entering a room. Draughts of the second kind are much more pernicious, because the air remains vitiated in spite of them. I could give you some conspicuous instances of them, particularly in certain places of worship ; the condensation of moisture on the windows of a crowded room affords ample evidence of the transmission of enormous quantities of heat, which must produce dynamical effects. I should like to see these removed by catching the cold air as it descends along the windows and removing it from the building by extraction openings under them ; but if this cannot be, warming arrangements under the windows can be made to compensate for the loss of heat, and the dynamical effects can thus be avoided.

VII.—Examination of Arrangements for Ventilation.

I turn next to the consideration of the mode of examining the ventilation of a building either actually constructed or in plan. This is a comparatively simple matter. Taking each room in turn, consider what are—for that room—(1) the inlets, (2) the outlets, (3) the motive power, in summer and in winter. It will generally be found that the motive power is restricted to the inlets or the outlets, generally to a single channel. In that case the correct action of other openings originally intended for the same purpose is less than doubtful. Having identified the motive power, it is next important to ascertain the volume of the ventilation currents as measured either in the inlets or outlets. Then the temperature of the entering air and its quality should be examined.

These items can all be very rapidly determined. For example, if a school class-room has a single fire, no special opening except windows and a door to a corridor, you may take the fire as requiring from 10,000 to 15,000 cubic feet of air per hour. This comes either from the windows, the corridor, or the chinks, and an estimate of the temperature and of the quality of the air coming in is then easily made. One open fire for five or six boys without any other provision might give tolerable ventilation. If you find a single open fire ventilating a class-room for

twenty boys, you have still something to think about in the matter of ventilation.

VIII.—Details.

With this mode of examining and tabulating ventilation requirements in view, I may now refer to a few points in regard to the different types of rooms that you have to deal with.

For dormitories I must confess that the causes which make for the mixing of air are so many and so vigorous that from the point of view of effective isolation separate rooms for the boys with separate inlets and outlets are unavoidable *desiderata*. This may be a counsel of perfection, and the advantages of isolation may have to go in consideration of other matters, but if not a separate room for each boy, then as few boys as possible in each room is a clear necessity. I should like to suggest an experiment in this matter for your consideration. Set your dormitory ventilation at its best and light a pastille, or place some evil smelling compound in the dormitory—the boys will suggest one if you are unable to do so—and ascertain whether your ventilation arrangements prevent the smell diffusing over the room.

I will add a word as to closets: it is usual to leave them cold and trust to open windows for their ventilation. They nearly always act as inlets to the adjoining buildings. The obvious plan is to make them the locus of vigorous extraction shafts, and as you remove certain waste products in one direction remove the air in another. Let these outlets be fed by air from the passages so that the direction of flow is from the building to the outlets in the closets, and not the reverse. For some reason or other it has generally been regarded as necessary to put apparatus for extracting air into immediate connexion with the room to be ventilated. In consequence the room is apt to become the receptacle for all the specimens of air that have nowhere in particular to go to, and the air which finds its way into closets is one of these specimens. The extraction apparatus might be quite as effectively employed for its purpose if the closet formed the lower portion of the extraction arrangement.

In the ventilation of chapels you have quite an open field. I am acquainted with one church which has a most amusing provision for ventilation. To the best of my recollection it consists of eight 3-inch square openings in the sills of the windows, four on each side, communicating with 9-inch airbricks outside, several feet below. With an unusually strong wind, if the channels are not blocked with builders' rubbish, one of these openings might deliver air for a single person. In all, a congregation of four persons is provided for: but if anyone complains that a congregation of two hundred find it

impossible to stay out the service, the special provision for ventilation is pointed to in triumphant vindication of the careful foresight of the designers. No church that I am acquainted with has really attempted to provide air for its congregation. The aëromotive force is derived from the difference of temperature within and without the building, or from wind ; the inlets are such doors or windows as happen to be open—chinks do not count where a large congregation is concerned—the outlets are whatever the air can find in the roof or the upper windows. If you can give school chapels their due in the matter of fresh air you will initiate a new and most valuable departure in ventilation.

As for studies, if a study has a fireplace, and a fire in it, you may rely upon its being ventilated for four persons or thereabout. If it has no fire it would be well to consider what the aëromotive force is which produces ventilation. If the heating is by hot water the amount of opening required to ensure an adequate supply of air is so large that we approach the open-air system.

I have not dealt with this system. I have supposed it not strictly included among systems of ventilation. It may, after all, be the proper plan to adopt ; but, regarding the matter purely from the point of view of history, without any scientific refinements, I suppose our ancestors tried it, and preferred tuberculosis. They may have been unwise.

Report of Discussion on MR. SHAW'S *paper*, "*Ventilation as a Dynamical Problem*," *delivered at an ordinary meeting of the Society, on February* 6*th*, 1902, *at the Medical Rooms, Chandos Street, W.*

THE PRESIDENT, in opening the discussion, said the paper was extremely interesting. The subject was a large and complicated one, and he did not intend to intervene in any way between Mr. Shaw and those who were prepared to discuss the paper. He, however, ventured to call attention to the fact that the discussion was on the Ventilation of School Buildings, with special reference to its application to existing buildings; and speakers were asked, as far as possible, to give the meeting the advantage of their actual experience of systems of ventilation, how they have failed or succeeded, and general opinions on the whole subject.

DR. CHILDS said they were all very much indebted to Mr. Shaw for his interesting paper, which had given them a great deal to think about. Not only were they indebted to him on this occasion, but also for having placed the whole subject of ventilation on a scientific basis, and on a far higher platform than they were usually accustomed to adopt in discussing this very complicated question. Mr. Shaw has shown definitely, and has emphasised the fact, that the movement of all air currents is regulated by given physical laws. He has shown that it is not simply a question of sticking on some patent cowl or similar apparatus to bring about a complete and efficient system of ventilation. He hoped that the members of the Association might be able to make observations on their own account with regard to ventilation in public schools. The Association can really do nothing more useful at the present time than to obtain the results of observations, and draw up certain rules which will be useful to all of them in deciding the practical details of ventilation. They were asked that afternoon to discuss the question from the public school point of view, more particularly with regard to buildings which have been already constructed. The question of ventilation, as has been pointed out, is generally the last matter thought of in the construction of a building. Unfortunately, the ventilation and lighting and warming of buildings are hardly ever considered together or by the same individual. Most deplorable of all, the medical officer of the school is the last person the authorities consult. Ventilation arrangements are generally left to the architect, with the result that the necessary alterations which the medical officers request have to be made subsequently at great expense. Before constructing school buildings, ventilation should receive its due consideration, and the medical officer of the school should be con-

sulted with regard to the requirements in this respect. In discussing public school buildings they would have to consider especially the ventilation of dormitories, classrooms, chapels, and studies. He noticed that Mr. Shaw had not mentioned the subject of cubic space. Presumably, this had been because there is nothing more to be said about the matter. They, however, were conscious that authorities, or reputed authorities, differ a good deal with regard to this subject of cubic space. Speaking in a general way, one has to admit that in public schools, the cubic space of classrooms and dormitories is often far below what it ought to be. He hoped for an expression of opinion from Mr. Shaw and others who have studied the subject as to what should be really the minimum cubic space in classrooms, dormitories and studies. When he was medical officer of a school he had laid down as a rule that the minimum allowable for dormitories should be 750 feet, but the minimum desirable should be 1,000 feet. They should get 1,000 feet if they possibly could, but 750 feet should be the lowest allowable. He was afraid that even the minimum allowable is rarely obtained in the majority of our public schools. Turning to the classrooms, the Board School minimum is 10 square feet of floor area. That means practically 120 to 130 cubic feet. What is the minimum that should be aimed at in regard to this floor area in order to secure proper ventilation in the classrooms of our public schools? With regard to the method of ventilation of schoolrooms, his observations had been chiefly in connection with the ventilation of Board Schools. He had an opportunity of investigating the conditions of ventilation in a considerable number of Board Schools in Scotland and in Leeds, together with some Board Schools in London. The conclusion he had come to was that for schools of this class the Plenum system is far better than any other system that has been hitherto contrived, such as a thermal or natural system. It was to be hoped that they would hear from Dr. Glover Lyon something about his means of distributing the air by a combination of graduated inlets and outlets, and the Plenum and exhaust systems. He noticed that Miss Ravenhill, who had been in America, was present, and possibly she would be able to give them some useful information: for instance, the air in the schools of America was maintained at a much higher temperature than is the case in this country. There, 70 degrees F. was the average. In concluding, Dr. Childs expressed the hope that the meeting might be the beginning of a real practical study by the Association of a very complicated but important subject connected with our public schools.

Miss Alice Ravenhill said that her study of schools in America had been so compulsorily limited by the wide scope of the commission entrusted to her that she could not contribute very much to the discussion. She had been impressed by the large allowance of cubic space (250 cubic feet) which appeared to be the usual allowance in all new schools in the United States. The Plenum system of ventilation is looked upon almost as a necessity for all large schools, or rather a combination of the Plenum with the vacuum system. The best authorities on school hygiene agree that where air has to be propelled through shafts of considerable length, and then passed through a large room and up an extract shaft, propulsion alone is insufficient to ensure

satisfactory circulation. The loss of momentum through friction and other causes must be made good by the provision of some mechanical aspirating power in connection with the main extract shaft. As a result of this opinion, she found small aspirating fans fixed in the extract shafts of the best schools to supplement the work of the large propelling fan. An excellent point in connection with this combination method of ventilation is that windows can be opened in any part of the building without interfering with the successful working of the system. This is not allowable where the Plenum system alone is installed, as the air must enter rooms under a slight pressure, with which the opening of even one window interferes. She found her own opinion shared, viz., that the effect on young people of attending schools where the windows are hermetically sealed is unsatisfactory. Teachers rarely take the trouble to explain how ventilation is secured, and the children, accustomed to the sight of closed windows, lose useful training in hygienic habits. Another objection is also raised to the adoption of the pure Plenum system: there are very few buildings which are not the better for free flushing at intervals by currents of air through open doors and windows, but this is an impossibility where windows are not made to open.

A decided opinion is held by some U.S.A. experts that certain sensations of draught experienced in mechanically ventilated buildings might be obviated if two or more smaller outlets were provided in each room, instead of one large one as is now usual. This is a point she would very much like to hear discussed. She had had no opportunity of observing a building where this arrangement has been adopted, but she did know several mechanically ventilated schools in England where there is a very perceptible current of air experienced by the scholars sitting in line with the one outlet; especially does this appear to be the case in rooms where there is a considerable expanse of window on the opposite side from which the air enters. The air, being propelled into such rooms at a considerable velocity, impinges on the cold surfaces of the large windows and then passes in a very chilled state up the extract shaft, causing such discomfort to those sitting in its track, that, in order to mitigate the nuisance, the extract shaft is often temporarily closed up, thus, of course, defeating the principle of the system. Another development now advocated in the United States is that of having several small inlets as well as more than one outlet, in order to secure improved diffusion. It is thought that when air is admitted by only one large opening, it passes too rapidly to the opposite side of the room, and suffers from unequal distribution, whereas if it be admitted at several small inlets, of course, all at the same level, it would be better diffused. The ultimate economy of mechanical systems of ventilation is thoroughly recognised in the United States, and that view is supported in the cities in the north of England where a sufficient length of time had elapsed since installations had been made to enable authorities to strike averages. All evidence pointed to the fact that the working expenses of these systems are very reasonable indeed; it is the first installation that is financially costly.

She wished to ask if a portion of the draughts so often complained of by the occupants of mechanically ventilated rooms is not possibly attributable to the fact of the air entering without a sufficient admixture

of humidity. In her own experience in the North of England (and she heard the same complaints in the United States), when the air outside has had its temperature very much raised (say 40 to 50 degrees F.), and is insufficiently humidified, it causes such rapid evaporation from the bodies of the occupants on entering a room, that they experience a sensation of draught and discomfort, when no "draught" in the accepted sense of the term exists, and thus a valuable system is discredited. In U.S.A., the air is scarcely ever humidified in their mechanically ventilated buildings, though great diversity of opinion exists on the point. Some professors of sanitation consider it is detrimental to the health of the scholars to breathe this very dry air for a long time, say three hours at a stretch, and then to pass out to a much lower temperature with the air possibly saturated with moisture, while other high authorities consider this to be advantageous. She found it difficult to form a judgment on some of these points while in the States, because the exceedingly high temperature at which the rooms are kept (never less than 70 degrees F.) is so different from the English custom that a certain amount of adjustment to new conditions was necessary in order to make any observations worth recording.

She gained the impression that the control of mechanically ventilated schools in U.S.A. is more generally entrusted to skilled engineers than is the case in Great Britain, with great advantage. Almost without exception, on both sides of the Atlantic, she had heard objections raised by the teachers employed in these mechanically ventilated buildings to these methods of ventilation. They make much of the disadvantages, and are not apparently impressed with the improved hygienic conditions they should obtain from them. Complaints are common of sensations of depression and of feelings of exhaustion, which should certainly not be the case, in addition to the constant grumbling about draughts. She did not know whether it would be possible to obtain definite information from teachers over a wide area, in order to find out how much ground there is for this prevalent opinion. She raised the point because she was surprised to hear exactly the same objection emphasised in almost identical terms by teachers in the States as by those in England. She regretted that she could not contribute further to the discussion on the points raised by Mr. Shaw's interesting paper, but she appeared there that afternoon rather as a seeker after, than as a contributor of, information. (Cheers.)

Dr. Glover Lyon thanked the Society for doing him the honour of asking him to make a few remarks. He felt grateful to Mr. Shaw for bringing forward the paper in the manner he had done, partly because it was very thorough and partly because he had taken different lines from himself in trying to solve the problems of ventilation. He would like to mention one or two things which he deemed of the greatest importance. One good feature of Dr. Shaw's paper was the way he disregarded trifling things. The author scarcely mentioned the word diffusion, and he was perfectly right, for in regard to a crowded school room molecular diffusion can be neglected entirely. They all knew that people will complain of a draught in one part of a crowded room and another person sitting in a chair a little way off would complain of being suffocated. Another important point was the causes of air

vitiation. These were the loss of oxygen, the increase of carbonic acid, the increase of water, the increase of heat and also the appearance of substances we do not know what. These substances have no name, but he had suggested one, viz., spiro-toxins. They were poisons, and they were emitted from the breath through the mouth, and also from the skin. Different kinds are emitted during sleep and during waking hours. They all knew the peculiar smell of a stuffy dormitory which was quite different from the smell of a stuffy day room. He was inclined to think the smell came from the skin chiefly during sleep, and that in a crowded room in waking hours from the breath. A great deal of harm was done in talking about the splendid diffusing power of oxygen while people were being poisoned in a crowded room by these spiro-toxins which had an active depressing effect on the nervous system. A lady faints in a church; she is not suffocated or asphyxiated, as is generally supposed, but she is poisoned. In the same way the people in the Black Hole of Calcutta did not show symptoms of suffocation, they had symptoms of fever, that is that although the air was extremely humid they suffered the most dreadful thirst, and became maniacally delirious, rushed about asking the jailors to kill them, and so forth. That did not seem to be due to a want of oxygen, nor was it. Carbonic acid is almost harmless up to a certain point. Some people could breathe carbonic acid up to five per cent., but between five and ten per cent. death occurs. This fact is established by the experience in soda water manufactories. Although an increase of humidity in the air would to a certain extent cause discomfort he did not think it was harmful; he would, however, call attention to the analogy between these mysterious spiro-toxins and other mysterious substances which occurred in disease, for instance, in renal disease a patient will be going on fairly well and all at once will become comatose. Exactly the same sort of thing probably happens. Some mysterious unstable compounds are formed and poison the patient. In the same way is it with diabetes—sugar in the blood—the patient will be allright for a long time, but one day something or other will form, and the person becomes comatose. There is an analogy between the two kinds of substances which is striking. One of the chief things to remember about spiro-toxins is that they are extremely indiffusive. Really the problem of a crowded room is to remove the spiro-toxins and nothing else. Let them do that, and they need not bother about oxygen, water or carbonic acid. The next point might be theoretical, but he wanted to quarrel with Mr. Shaw a little bit in regard to the introduction of the analogy of electricity. He did not think that the electrical analogy was at all requisite, and the electrical diagram was rather puzzling. The speaker had taken different lines in trying to work out the problem, and that was by regarding air just as ordinary matter, having inertia and momentum. For instance, most people would be surprised to find that the air in that room weighed several tons. A bullet has momentum, it is stopped by a target, pressure is produced. In the same way if air is thrown along and stopped, pressure is produced. The air is then thrown out on all sides. Such an experiment gave the key to a very large part of the ventilation problem, momentum was turned into pressure and pressure turned back again into momentum. He was glad to find Mr. Shaw had not said much about natural systems. With regard to temperature in New York and the American schools

there air was kept at a temperature of seventy, and one reason for this was that it is much easier to keep air in a crowded room at seventy degrees that it is at sixty. Dr. Glover Lyon then proceeded by means of some simple illustrations, for which he utilised the walls of the room, to describe his system of inlets and outlets, a complete model of which with electrical fans was exhibited. The system he described satisfied the three conditions necessary to ventilation, as pointed out by Mr. Shaw. The size of the inlet is of enormous importance from the dynamical point of view, and if they had large inlets they must have large conduits, and the same with the outlets. Secondly, it was pointed out that diffusion is quite inert in the matter of crowded rooms, such as schoolrooms, so that the distribution of inlets, as he had suggested, answered that point; and thirdly, they wanted to have the ventilation without draughts. There again, the only way to get rid of draughts is to have large inlets and outlets. They must have large inlets and many of them if they wanted to escape draughts. Dr. Glover Lyon then proceeded to still further explain in detail his system of ventilation, and at the close of the meeting exhibited his apparatus. In concluding, he said that after many years' experience he could endorse Mr. Shaw's remarks about the architects. Sometimes he had been to the architect about the ventilation of the building, and the architect had replied that that question would come later on; and the next time he had seen him and mentioned the matter, the reply was "Oh, we have settled all that." There never appeared to be a right moment for architects to attend to ventilation.

Mrs. White Wallis said that it would be useful if they could get some further information on the difficult matter of small classroom ventilation. It should not be a difficult problem to solve for classes which were only required to hold fifteen or sixteen children. Yet with full allowance of cubic space and a good fire burning, it seemed a difficult matter to many teachers to properly ventilate a room with fifteen or sixteen children in it without opening the windows during the three-quarters of an hour of attendance in the classroom. It was found a difficult matter to keep the air constantly fresh and at the same time the rooms warmed to fifty or sixty degrees. In America it was customary, as had been said, to keep the air of classrooms at seventy degrees, and if the temperature fell to sixty the schools were closed and the children dismissed; but in this country it was generally considered healthiest to keep classrooms between fifty and sixty degrees. The medical officers of schools in England had not, she believed, given any definite pronouncement as to the temperature at which the classrooms should be maintained, or stated the minimum below which the temperature should not fall, to secure the highest amount of mental activity. Mrs. White Wallis questioned Mr. Shaw's definition of a draught, asking, was it quite enough to define draught as cold air perceived in a vitiated atmosphere? Supposing the air in a room was pure and circulating freely from a window open at the top, and a fire drawing into the chimney from that and other similar inlets, and yet a window was open at the bottom and the cold air allowed to fall on the children sitting in the room: might not that be justifiably called a draught? In the open fresh air, Mr. Shaw said draughts, properly so called, did not exist,

therefore to avoid draught let them keep the air of rooms fresh. But directly we confined the air by walls we changed the conditions of outside ventilation and no longer had open air; and might not that be the explanation of the draughts in the garden, to which Mr. Shaw had referred, where the confining of air by means of high hedges and garden walls caused the sensation of draught, and produced the difficulty of keeping plants which had been referred to? Besides, was it not a little dangerous to say the perception of cold air formed a draught because what we needed was to get rid of the personal thermometer in these matters as much as possible, and to establish some health law that might be acted upon by those who had no time to go into the question thoroughly, and this in order to save many school children from the consequences of the lack of appreciation of what ventilation really meant. In the reaction from the close confined air of the vitiated atmosphere of crowded classrooms and in the desire to keep the air pure and fresh, teachers—even those who have undergone some sort of training—were apt to run away with the idea that to ventilate a classroom properly one has only to admit the largest possible amount of fresh air regardless of rain or fog and regardless of the temperature of the room in which the children were sitting, or the direction of the incoming air upon their bodies. The consequence had been, within her own experience, that many children suffered keenly from pleurisy and from neuralgia, and the cold air entering at too low a level caused inward chills which affected the glandular system, and were productive of great harm. She would be very glad if teachers could get some definite instructions from medical officers upon what should be the minimum temperature of classrooms, and how a fair sized classroom for fifteen or sixteen children might be provided with fresh air other than by mechanical ventilation or open windows.

Dr. Shelly said that, in his excellent paper, Mr. Shaw had brushed aside mere trivialities, and frankly showed them the exceedingly complex character of the problem they have to face, the difficulties they have to contend with, the manifold way in which those difficulties interlace; and also, if he might use a word coined to represent a compound of futile and puerile, the putile fashion in which it has often been attempted to deal with one of the most important problems connected with the erection of buildings of all kinds. It was not too much to say, for instance, that the very last thing considered in the arrangement, erection, and management of such buildings as churches, chapels, and the like, is the bodily health of the congregation. With regard to classrooms, studies, and similar rooms apt to be occupied during the evening hours, they were confronted very often with this problem. There was a considerable number of human beings in an enclosed space, heated by artificial light, generally by gas or paraffin; and if they used Mr. Shaw's steps and ascended, they would find the air near the ceiling top so foul that they would be glad to come down again. Heated and irrespirable air accumulated under the ceiling, and the question was what became of it? Now a very large proportion of that vitiated air finds its way through the porous plaster of the ceiling into the room above. If they analysed the air of a bedroom over a sitting-room with two or three gas burners in it, and compared the analysis with that of the air of a bedroom over an empty room,

they would soon realise the difference. It had occurred to him, and with increasing force of late years, that a desirable arrangement for schools would be to have all the sleeping rooms on the ground floor, and the classrooms and schoolrooms on the floor above. With such an arrangement, the vitiated air of the classrooms and schoolrooms would escape at night without injuring the sleepers, and the dormitories would be quite free from the impure air when they were required to be used. Again, the dormitories would easily be flushed with fresh air throughout the daylight hours, while schoolrooms, classrooms, and studies, if situated on the first floor, would have all the better opportunities of getting a supply of sunshine and fresh air during the hours of work, and that air would be of a better quality because obtained at a higher level. The question of fireplaces, and the part played by them in ventilation, was a very interesting one, and he would not have ventured to touch upon it but for the fact that the adaptability of the ordinary open grate is sometimes neglected in relation to the better ventilation of smaller rooms. Dr. Shelly then drew a diagram upon the blackboard showing how an open fire affects the ventilation of an ordinary room. He pointed out that it was chiefly fresh air, drawn in from chinks in the doorway and in the flooring, &c., and travelling below the level of the sitter's knees, which was used for securing and promoting the combustion of the fire. This stream of fresh air was not available for respiration, but it produced chilling "floor draughts"; and, if the windows were closed, currents of cold air from the window casings, drawn rapidly and directly towards the burning fuel, added other insistent draughts of air, relatively pure, but of comparatively little use for respiratory purposes. The discomfort thus produced often led to such chink inlets being stopped up (in order "to keep out the draughts"), and then the chimney was apt to smoke, because the fuel was starved of the oxygen necessary to its combustion. If now a small opening, about 3 in. × 3 in. be made in the hearth, communicating by a suitable conduit with the open air, or with a ventilated cellar, the fire burns brightly, and the floor draughts are abolished. Moreover—and here comes in the real gain—windows and ventilators may be kept open without discomfort, because the fresh air entering by these inlets now does so at a rate so much slower that it is not felt as an insistent draught, and has greater opportunities of mingling with, and healthily diluting the mass of heated and relatively foul air in the room. So that the occupants are led to tolerate a cooler and purer atmosphere, and an important step is taken in their hygienic education and practice. By adopting such a device, he had often succeeded in not only curing smoky chimneys, otherwise incurable, but had also been able to insure a much more healthy condition for occupants of rooms previously almost uninhabitable; and the plan was one worth bearing in mind when dealing with the ventilation of form and classrooms. It was not, of course, a direct means of securing the proper ventilation of a room; but it did substitute for uncomfortable draughts of fresh air (flowing at too low a level to be of any use for respiration) a condition of things which made possible the use of some "natural" means of ventilation without incurring thereby that discomfort which so often led to these means being deliberately abolished. As regards draughts, there was much

aptness in Mr. Shaw's definition, because it is just under those conditions in which we breathe vitiated air that our poisoned nervous system becomes peculiarly susceptible to the sensation of chilliness, and our bodies specially prone to suffer from the effects of chill. He desired to express his great personal indebtedness to Mr. Shaw and other speakers for their remarks that afternoon.

The President, in summing up the debate, said they had learnt a great deal that afternoon from Mr. Shaw's paper, and from the various speeches of the ladies and gentlemen who had favoured them with their views. He was very glad indeed to hear from Mr. Shaw that he gave a certain amount of praise to what is called the "happy-go-lucky system." That was practically the only system with which he had any familiar acquaintance. Although it was a very long time ago, he was quite certain that it was the "happy-go-lucky system" which was in vogue in the public school he was at, and certainly in that particular system it acted very well. The health of the boys was exceedingly good, and no doubt the explanation was that given in the debate, that it was new blood. Although he could not tell the exact amount, the allowance of cubic space was excellent, and the consequence was that the boys got along very well. One question of an allied character had not been touched upon. He thought that the great question in regard to the question of ventilation was that of warmth. If they could get the air sufficiently warm, the draughts would cease to be.

Mr. Shaw, in replying to the various points which had been raised, said in reference to Dr. Childs' suggestion as to cubic space he had already dealt with the matter in a published report on the Ventilation of Poor Law Schools. It seemed to him that the proper way was to treat cubic space from the point of view of ventilation. The ordinary practice was to measure the room, and supposing it contained 1,000 cubic feet, to say that therefore there was accommodation for so many persons; but they might come across cases of rooms with ample accommodation as estimated by this method where they ought to conclude that there was really no accommodation for anyone at all, because there was no provision for ventilation. The number of persons that could be accommodated in a room of one thousand cubic feet depended entirely on the amount of air which could be supplied continuously to the room and taken out again. It seemed to him the proper way to deal with the question was to go into the room and, supposing there was a provision of 10,000 cubic feet of air per hour, to say that the room would therefore accommodate three persons, assuming that each person took as his allowance about 3,000 cubic feet per hour. If they were to adopt that mode of dealing with the allowance of cubic space they would find the actual cubic space would work out large enough, because it was rather difficult to supply a sufficient amount of air for ventilation on that large scale; and if they had a provision of 3,000 cubic feet of air per hour for each person they might be quite sure that the dimensions of the room would be considerable. The proper way, then, was to go into the room and measure how much air was supplied, settling for themselves whether they wished to allow 1,000 or 3,000 cubic feet

per hour for each person. Opinions might differ upon that, and opinions might therefore differ as to the effective capacity of a room, but having arrived at this conclusion on the basis of the volume of air supplied, let the medical officer license the room for so many persons. He was quite sure that on this basis they would find it difficult to license a room for the number of scholars that school masters, generally speaking, desired to put into it.

With regard to Miss Ravenhill's remark as to currents and draughts under the plenum system, he had not noticed with the plenum system any special provision for avoiding the effect of cold windows in producing draughts. Cold window surfaces were productive of a considerable amount of definite draught, and he presumed the Plenum system required to be modified to take account of that in order to avoid what is obviously a source of difficulty in a country where you might have the thermometer in the outside air somewhere in the neighbourhood of the zero point for a considerable time. Miss Ravenhill also spoke about the dryness of the air; he was not aware that there were any sufficient observations or statistics about the alleged deleterious effect of the dryness of the air. He thought that was a matter for medical officers of health to determine. His own impression was that dry air was not uncomfortable, and it was only dry air indoors that had the reputation of being extremely disagreeable. With dry mountain air nothing disagreeable was experienced, and no one complained of its dryness. Extreme dryness of air was generally regarded out of doors as brisk and exhilarating, and not as pernicious. He was not at all sure that the surfaces over which the air passed in being warmed might not account for the objection to the warm air in buildings on the ground of its dryness. Saturation was effected by the body, that is to say, the air in passing into the body was presumably saturated by the moisture of the passages. Cold air being inhaled had to be both warmed and saturated; if previously warmed, less heat but the same amount of moisture would have to be taken from the body. As to the feeling of depression and exhaustion spoken of by Miss Ravenhill in referring to the plenum system, he would put a suggestion to the members. The human body did not like absolute uniformity. If the plenum system was worked up to its ideals, it gave air always at the same temperature, the same degree of moisture, and of the same composition. That is to say, the system put them in the position of being supplied with absolute uniformity. Now medical men ought to know about these things; he did not know, but it seemed to him that the human body liked change, and was not disposed to accept a persistent supply even of a good thing. Sometimes it liked the air to be colder, sometimes warmer. Sometimes one liked to have a room down to 50 and sometimes up to 70, and when they were obliged to have it always at the same temperature, then there might be some complaint owing to the persistent uniformity of the conditions. For that reason, he thought arrangements should be made to have the pressure in a room neither above nor below that of the external air, so that windows might be opened at will without causing interference with the ventilation of the whole building; there should be neither plenum nor vacuum in the ventilated space. Such a system he had been accustomed to call a zero potential system for

reasons based upon the electrical analogy which he would not stop to explain.

Dr. Lyon had suggested that the electrical analogy was not appropriate. He thought Dr. Lyon had in mind more particularly the currents of air in the ventilated space. The analogy was more specially applicable when a number of connected rooms was under consideration. The other day he had been called upon to advise upon plans for the ventilation of the out-patient department of a very large hospital. There were, perhaps, some 300 rooms on three floors, with windows, air gratings, doors, passages, corridors, staircases and lifts. It was a difficult problem, and the probable mode of working of the system was unintelligible to him until the possible circuits of air currents had been marked down in order that some sort of picture could be formed of them ; no doubt it was an extremely complicated one, but it was a picture from which one could get a definite idea of the way things would act, even in a complicated plan. The analysis of the ventilation of an elaborate building was a most complicated problem, and he did not believe its solution was possible with any degree of accuracy or satisfaction, unless some sort of picture was obtained more simple than the architect's plans with all the architectural details. It was for that reason that he had used the electrical analogy for the purpose of describing something which otherwise it was almost impossible to describe.

Mrs. White Wallis had demurred to his definition of a draught, but he did not mind that in the least, for he did not attach any final importance to his definition. What he wanted to point out was that in his experience cold air could injure him in two or three ways, and so produce different kinds of disease. He thought there ought to be some practical definition for practical ventilators, some distinction between currents of air that were associated with poisonous conditions and currents of fresh air that simply reduced temperature, such as are felt in the open air. It was for that reason that he had limited the definition of a draught to the perception of cold air in an unventilated or badly ventilated space. Probably the physiological effects under the circumstances differed. There was another effect of cold air in an enclosed space, to which he had not referred ; that is to say, one part of the body might be kept persistently cold, while another part would be warm. He did not know how the human body accommodated itself to this state of things, but, at the same time, he thought there was a marked distinction between the effect of a draught in an ill-ventilated space and the effect produced by an air current out of doors. Whether to the latter the term draught ought to be applied he could not undertake to say. Mrs. Wallis also asked a question with regard to the ventilation of classrooms occupied by fifteen people when there was no means of warming the entering air. He was afraid that was a very difficult thing ; in fact, to accomplish that was next door to the impossible. A classroom for fifteen persons should be provided with some 40,000 cubic feet of air per hour ; to maintain the requisite supply of air, the up draught of three ordinary chimneys would be required. He knew no means of introducing 40,000 cubic feet of cold air into a room of moderate size and disposing of it in such a way that the room would be comfortable for those persons who were liable

to feel cold. With regard to Dr. Shelly's illustration, he was reluctant to allow some 1,000 cubic feet per hour of good fresh air to be sent up the chimney without affecting the room at all. He would prefer some plan by which the air could be warmed and utilised for the purposes of ventilation.

A hearty vote of thanks was then accorded to Mr. Shaw for his paper, and the proceedings terminated.